

Effects of Offshore Forcing in the Nearshore Environment

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LONG-TERM GOALS

The broad objective of the project is to extend our understanding on the role of offshore baroclinic forcing in nearshore dynamics. From this understanding we aim to develop modeling approaches that, combined with offshore baroclinic models, can account for the effects of offshore internal wave forcing on the circulation and sediment transport in the coastal zone.

OBJECTIVES

Specifically, the work aims to address two questions:

1. How is offshore baroclinic tidal energy manifested in the nearshore environment, i.e. what is the transfer function between internal tides and nearshore currents?
2. What is the role of baroclinic tidal energy in nearshore circulation and, subsequently, on sediment transport?

The work focuses on real-time observations combined with event-driven sampling methodology to highlight the role of offshore tidal and wave forcing in the circulation and transport dynamics in the nearshore. Important secondary objectives include validation of the Delft3D model in capturing the effects of baroclinic forcing and predicting hydrodynamic circulation and sediment transport in the spatially complex environment posed by a carbonate reef.

APPROACH

Field observations of the nearshore response to offshore forcing are being carried out on the south shore of Oahu, focusing on the Kilo Nalu Observatory (<http://www.soest.hawaii.edu/OE/KiloNalu/>) located on the south shore of Oahu (Figure 1). The field work is being carried out in parallel with development of a nested, high-resolution numerical model for the study region.

Baroclinic motions in Mamala Bay offshore of Kilo Nalu have been observed to induce magnified isopycnal displacements as high as several hundred meters. The baroclinic motions associated with these displacements drive currents that are often several times greater than barotropic tidal currents. In addition to significant forcing from baroclinic sources in Mamala Bay, Kilo Nalu is subject to seasonal surface wave forcing from distant southern hemisphere sources, northeast trade swell wrap and onshore 'Kona' storm winds.

The observatory presently includes a cabled node at 10 m depth (~0.4 km from the shoreline) providing data and power connections for up to 4 subnodes (24/48V DC). The Kilo Nalu observational infrastructure is being expanded as part of an NSF CoOP project to provide power and real-time data access beyond the present 10 m node, in support of detailed observations of benthic boundary layer processes. The expanded observational array will include thermistor chain moorings at 10 m and 30 m depths along with a Seahorse profiling mooring at 20 m depth. An array of bottom mounted ADCPs will monitor currents and waves in real-time at 10 m, 20 m and 30 m depths. As part of the ONR funded work, the expanded Kilo Nalu array will be augmented by an additional thermistor chain/ADCP mooring at 40 m depth along with a string of bottom-mounted temperature and pressure sensors extending to 70 m depth. The extended thermistor chain array will enable accurate measurement of baroclinic energy fluxes across the shelf. The ADCP array at Kilo Nalu, combined with an array of autonomous wave gauges will provide nearshore wave characteristics for model comparisons.

A dedicated series of experiments are planned for summer 2007. These will include an array of wave gauges to be deployed along the 5m isobath beginning at the Kilo Nalu line and extending eastward to collect directional wave data along with near-bed currents. These will further serve to establish the spatial structure of the currents, in combination with spatial surveys using a REMUS AUV. The nearshore observations will be augmented with an offshore profiling mooring to be deployed in collaboration with Matthew Alford (UW APL).

A 4 km resolution regional model for Oahu including Mamala Bay, based on the Princeton Ocean Model (POM), has previously been developed in support of the NSF-funded HOME study. A high-resolution (1 km horizontal spacing) model of the Mamala Bay region, offshore of the south shore of Oahu has also been developed. A nested modeling approach will be used to specify the nearshore internal tide. The regional HOME model will provide boundary conditions for an updated 1 km POM run spanning the Molokai Channel. The channel run will capture the main features of the offshore internal tide as it propagates westward from the primary generation site on the east side of the channel.

Nested within the channel model will be a higher-resolution (20m) inner-shelf model with which we will specify the internal tide at the Kilo Nalu test site. Initially, we will simulate the nearshore internal tide using the boundary conditions provided by the channel run (i.e., the nearshore model will not feedback into the channel model). We anticipate that the details of the nearshore stratification, specified with the Kilo Nalu measurements, will strongly dictate the shallow water structure and shoreward penetration of the internal tide. For example, wind-driven currents that lead to a shoaling of the thermocline toward the coast may enhance the nearshore internal tide.

The goal for the nested model is to capture the "mean" internal tide and to explore the physical parameters most conducive for variations from that mean (a key element of the observations to date). Depending on the results from the nested model-data comparisons, a more ambitious data assimilation

approach may be used in which the Kilo Nalu measurements are used to nudge the nearshore model simulations to the observed internal tide structure.

The basic description of the internal tide and its temporal and spatial variability in the vicinity of the Kilo Nalu Observatory given by the larger scale models along with field observations will be incorporated into Delft3D runs (model domain depicted in Figure 2) for the purpose of examining the combined effect of tide and wave forcing on sediment transport. A series of Delft3D runs will be made for a full range of tide and wave conditions. In particular, modeling will focus on the larger swell events during the summer that are conducive for sediment suspension and transport. We anticipate that the details of the transport will be influenced by the strength and phase of the nearshore internal tide currents.

Observations of sediment transport within the model domain will focus on a sub-region of the study area to be selected from sidescan data.. The transport will be gauged using an integral approach based on REMUS sidescan and ship-based multibeam surveys.

Pawlak is been overseeing field data analysis and field operations in support of the work. Merrifield is managing model development and field data assimilation. Two postdoctoral researchers Judith Wells and Glenn Carter, are supported in part by the ONR project. Wells is carrying out analysis of archived Kilo Nalu data. Carter is carrying out large scale model development that will be integrated into the smaller scale model. An Ocean Engineering PhD student, Marion Bandet Chavanne is partially supported (25%) by the project. She is carrying out analysis of wave and current boundary layer dynamics that will provide friction parameters for modeling efforts. A graduate student, Sean Vitousek, funded separately and supervised by Chip Fletcher (UH Geology), has been developing application of DELFT3D for the study site. A new postdoctoral research has been recruited and will begin working full time on the project in November 2006. The project is also providing partial support for two research technicians, Kimball Millikan and Joseph Shacat, who are integrating instrumentation with Kilo Nalu and carrying out field operations.

WORK COMPLETED

The initial stages of the project have focused on development of the broader scale model components along with preliminary DELFT 3D modeling. Analysis of field data from Kilo Nalu is presently underway to determine the temporal structure of internal tide forcing in the nearshore. New field work will begin in Fall 2006 when the new Kilo Nalu observational infrastructure is deployed.

A series of simulations have been conducted as part of NSF funded work to determine the best open boundary conditions to use for regional simulations of internal tides. Code development was undertaken to allow the simulations to be conducted locally, rather than on a supercomputer as in the HOME project. This allows us more control and longer run times. A high resolution (one hundredth of a degree) model is presently being developed for the main Hawaiian Islands excluding the Big Island (figure 2). This domain not only allows simulation of all generation regions affecting the south shore of Oahu, but also importantly allows the open boundaries to be in deep water where the Topex derived barotropic currents are most accurate.

Preliminary modeling is being carried out using DELFT3D. Field observations in Fall 2006 will provide realistic boundary conditions for barotropic tidal forcing. Appropriate baroclinic boundary conditions will be determined large scale modeling combined with field observations.

A REMUS AUV has been modified to integrate a Seabird-49 FastCAT CTD which will enable high resolution spatial mapping of baroclinic structure in the nearshore zone. Spatial surveys within the DELFT3D model domain using the modified vehicle are planned for November 2006, coinciding with NSF funded observations at Kilo Nalu.

IMPACT/APPLICATIONS

Understanding of the relation between internal tide dynamics and nearshore processes is critical for accurate modeling of currents and sediment transport in the coastal zone. An important objective of the ongoing work is also to provide a qualitative assessment of the DELFT 3D model as a tool for predicting circulation and sediment transport in the spatially complex environment posed by a carbonate reef.

Our observations and modeling efforts are aimed at generating observational and numerical model data that will be of value for broader research and engineering applications. Data from regular REMUS AUV sidescan will also provide observations of ripple characteristics over a wide area. These observations, combined with current data will enable detailed assessment of ripple dynamics models.

The ongoing work is also supporting extension of the cabled Kilo Nalu Observatory baseline infrastructure. Kilo Nalu has enabled real-time access to data, facilitating deployment of instruments that would otherwise be limited to short-term deployments. The initial Kilo Nalu infrastructure was deployed largely with support of earlier ONR grant

RELATED PROJECTS

The work here is closely integrated with an NSF project, funded under the Coastal Ocean Processes (CoOP) program. The NSF work is funding an expansion of the Kilo Nalu Observatory including new baseline infrastructure extending to 30 m depth. The work aims to examine the response of benthic boundary layer geochemical fluxes to physical forcing including surface waves and internal tides. The observations being undertaken as part of that work complement the broader scale field data collected for the ONR work. In particular, observations on small scale boundary layer processes will provide input to nearshore modeling using DELFT3D. Near-bed bistatic current Doppler velocimeter (BCDV) observations by Tim Stanton (NPS) will also provide data on sediment transport processes relevant to the ONR work.

A NOAA Sea Grant funded project targeting nearshore water quality variability is also ongoing at Kilo Nalu. Water property observations collected as part of that work will also yield information on baroclinic processes at the study site.

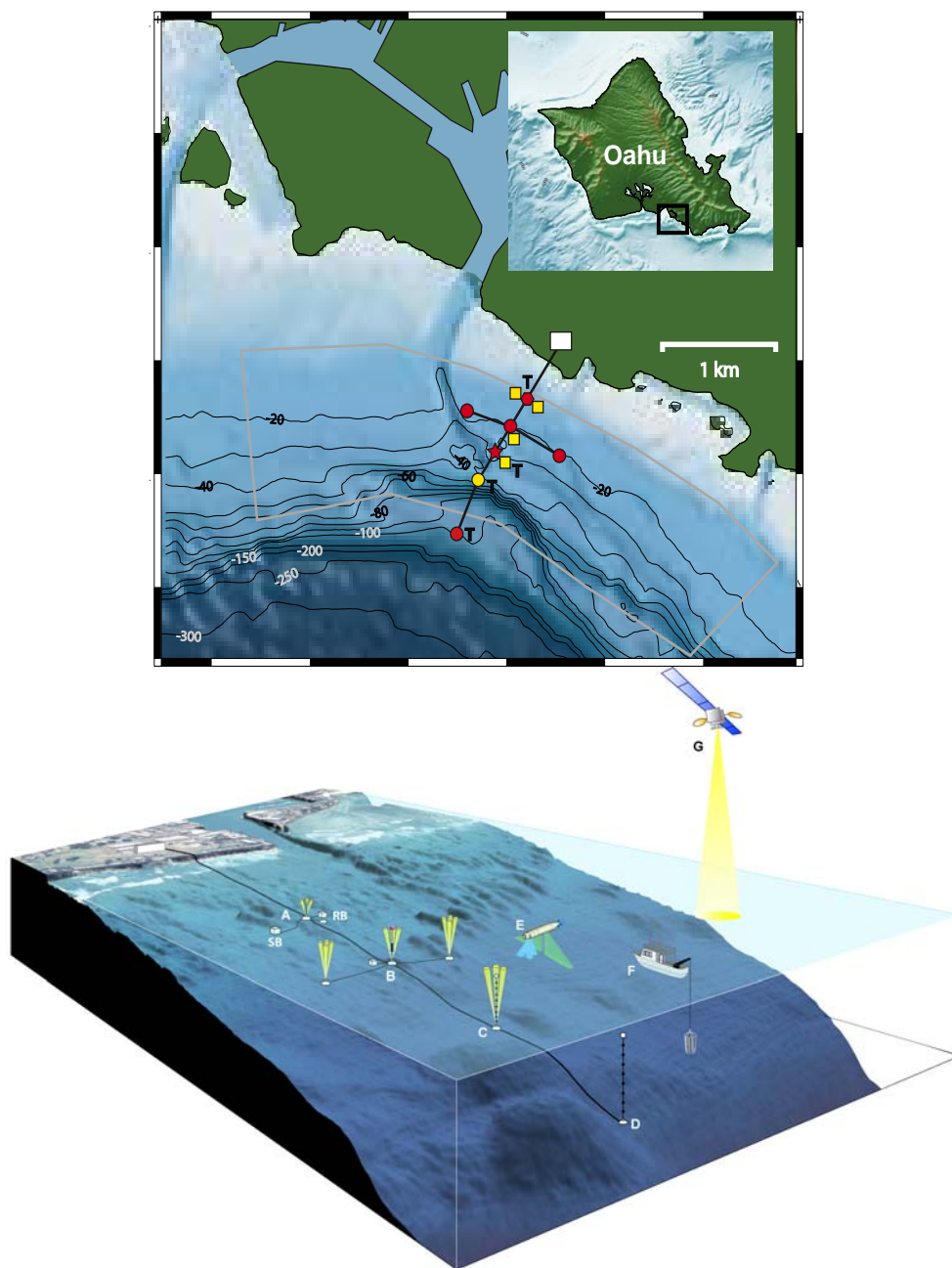


Figure 1 – Above: South shore of Oahu with Kilo Nalu site with AUV sampling domain (gray outline). Below: Overview of Kilo Nalu Observatory with observational layout including 10 m node (A); 20 m node (B) with lateral subnodes; 30 m node (C); 40 m subnode (D); REMUS AUV spatial sampling (E); ship-based sampling (F); and satellite-based remote sensing (G).

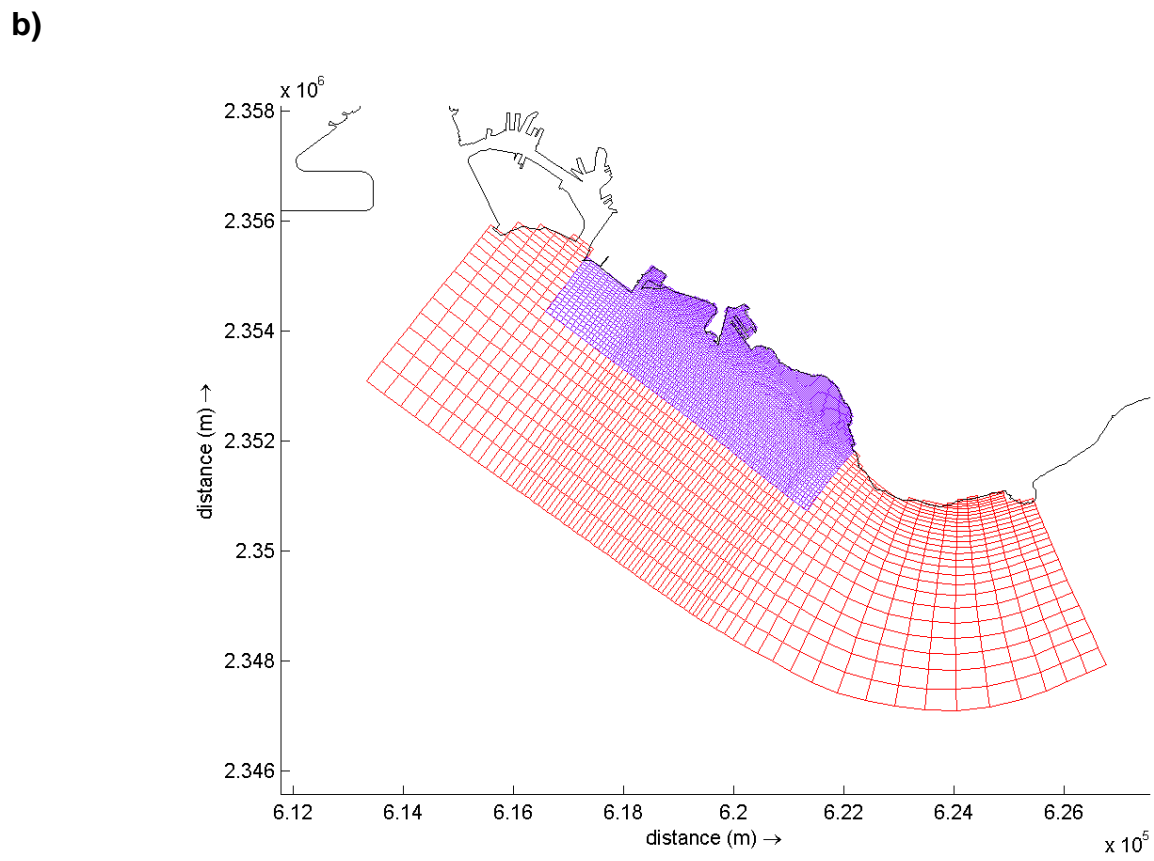
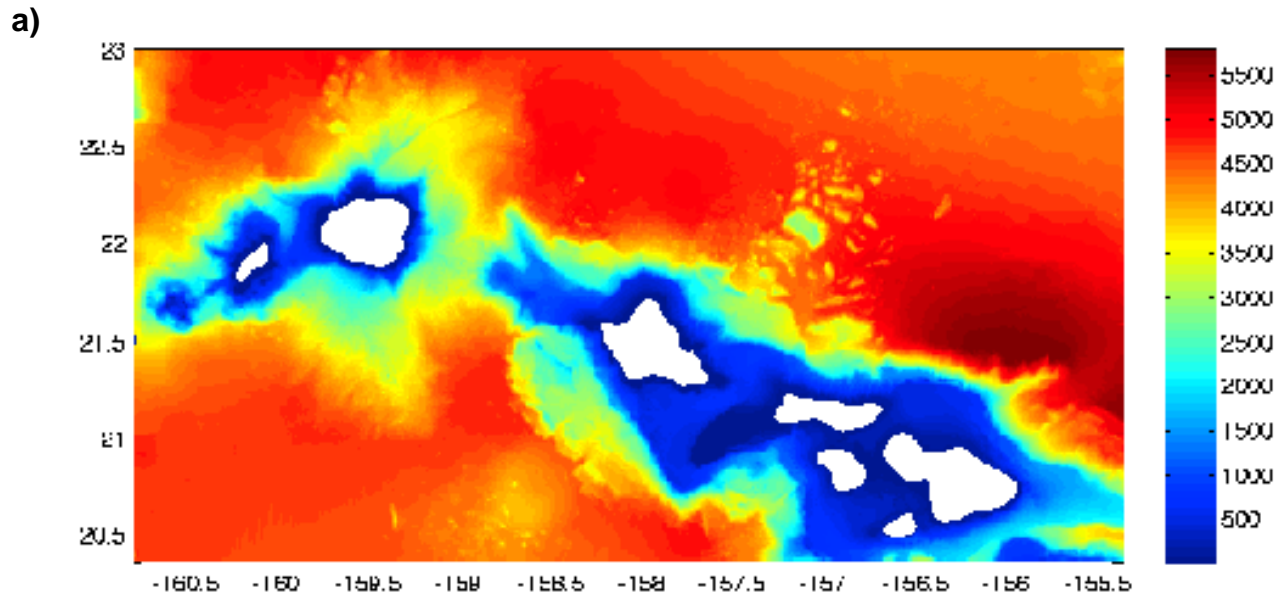


Figure 2: Numerical model domains for broad scale (a) and local scale (b) regions.